

# COSMOLOGY WITH GTC. A COMBINED MM-OPTICAL GALAXY CLUSTER SURVEY

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## RESUMEN

El satélite para el estudio del CMB, Planck (ESA), originará un catálogo con  $\approx 30000$  cúmulos de galaxias (efecto Sunyaev-Zel'dovich) entre redshifts 0 y  $\approx 2-3$  (dependiendo del modelo cosmológico). Tal extenso catálogo de cúmulos permitirá llevar a cabo estudios muy detallados de la evolución de la población de cúmulos con el redshift lo cual permitirá a su vez afinar en la estimación del modelo cosmológico. No obstante, la identificación de los cúmulos mas distantes tendrá que ser llevada a cabo con telescopios ópticos de gran diámetro (como GTC) ya que Planck no será capaz de dar una estimación del redshift de los cúmulos. En este trabajo mostramos como sólo hace falta identificar una pequeña porción de  $\approx 300$  cúmulos (que hayan sido seleccionados aleatoriamente del catálogo de Planck) para distinguir modelos que tienen o no tienen constante cosmológica.

## ABSTRACT

The CMB Planck satellite (ESA) will provide a catalogue of  $\approx 30000$  galaxy clusters (Sunyaev-Zel'dovich effect) between redshift 0 and  $\approx 2-3$  (depending on the cosmological model). This huge catalogue of clusters will allow detailed studies of the evolution of the cluster population with redshift which will constrain the cosmological model. The identification of the high redshift clusters should be done with a large telescope (like GTC) since Planck data alone will not provide any clue about the redshift of the clusters. In this work we show that an optical follow up of only  $\approx 300$  clusters (randomly selected from the Planck catalogue) is needed in order to distinguish models with or without a cosmological constant.

**Key Words:** COSMOLOGY: LARGE-SCALE STRUCTURE OF UNIVERSE, GALAXIES: CLUSTERS: GENERAL

## 1. INTRODUCTION

Clusters of galaxies have been widely used as cosmological probes. Their modeling can be easily understood as they are the final stage of the linearly evolved primordial density fluctuations. As a consequence, it is possible to describe, as a function of the cosmological model, the distribution of clusters and their evolution, the *mass function*, which is usually used as a cosmological test. Therefore, a detailed study of the cluster mass function will provide very useful information about the underlying cosmology. Unfortunately, cluster masses can not very well determined for intermediate-high redshift clusters and even for low redshift ones the error bars are still significant. However, instead of the mass function, it is possible to study the cluster population through other functions like the X-ray flux or luminosity functions, the temperature function or the Sunyaev-Zel'dovich effect (SZE hereafter) function. The advantage of these functions compared with the mass

function is that, in these cases, the estimation of the X-ray fluxes, luminosities, temperatures or SZE decrements of the clusters is less affected by systematics than the mass estimation. The largest catalogue of clusters in the next years will be provided by the CMB satellite Planck. It is expected that Planck data will contain about 30000 detectable clusters (see Diego et al. 2002).

The decrement in the CMB temperature due to the SZE is independent of redshift. Therefore the most distant clusters could be detected through the SZE. Hence, the SZE is the perfect way to look at those high redshift clusters. It is in the high redshift interval where the differences among the cosmological models are more evident when one looks at the cluster population.

Unfortunately, through the SZE it is not possible to measure the redshift of the clusters and an independent observation (in the optical waveband for instance) of the clusters is needed in order to estimate their redshifts.

Since many clusters will be at high redshift, a telescope with a large diameter (like GTC) will be

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needed in order to identify those high- $z$  clusters. However, due to the large size of the Planck catalogue, any proposal which attempts to make use of a 10-m class telescope to identify 30000 clusters would be rejected (even in the case the proposal plans to observe only the high- $z$  clusters there would be thousands of them !). In the next sections we will show how an SZE-selected optical survey made with GTC of only a small portion of the clusters in the Planck catalogue could be enough to obtain important cosmological constraints.

## 2. A COMBINED MM-OPTICAL SURVEY

At the end of this decade, the Planck satellite will carry out a full-sky survey in order to measure with a high sensitivity the CMB. However, other emissions (not only due to the CMB) will also be present in the data. Most of this non-CMB emissions will come from our own Galaxy (dust, free-free, synchrotron) but there will be also some extra-galactic emissions (point sources and the SZE). The wide frequency range, angular resolution and high sensitivity of Planck will allow to detect  $\approx 30000$  clusters.

Observing galaxy clusters in the mm sub-mm band through the SZE has a unique advantage. The amplitude of the decrement in the center of the cluster is independent of its redshift. Due to this fact, the catalogue of clusters obtained by Planck will have a privileged selection function and the proportion of high-to-low redshift clusters will be maximum if we compare the catalogue with others obtained in optical or X-ray surveys.

Galaxy clusters are the best tracers of the large scale structure and by studying the evolution of their abundance with redshift it is possible to impose very strong constraints on the cosmological model. For instance, using the local abundance of clusters it has been possible to find a strong correlation between the amplitude of the power spectrum ( $\sigma_8$ ) and the matter density ( $\Omega$ ). However, all the models in that correlation having different values of  $\sigma_8$  and  $\Omega$  predict the same observed local abundance of clusters (within the error bars). Therefore, by using just the local abundance of clusters it is not possible for instance to rule out models with high or low values of  $\Omega$ . However this can be done if we go back on time and study the evolution of the cluster abundance with redshift. In this case, the further we go in redshift, the better are the constraints in the cosmological parameters.

As we have mentioned, the selection function of Planck will be privileged in the sense that the

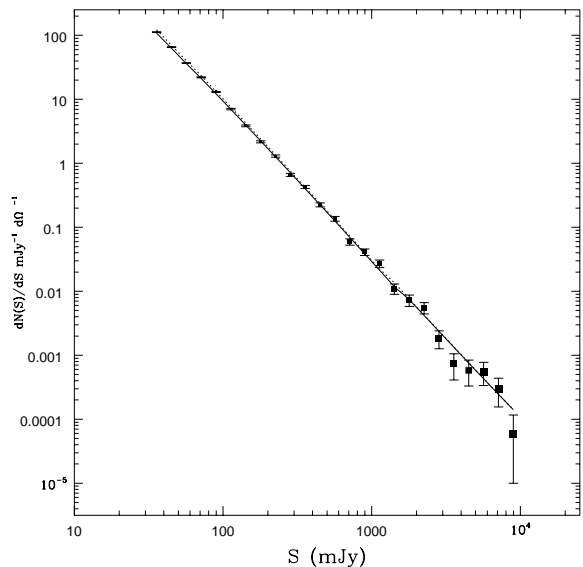


Fig. 1. Cluster number counts for Planck. Two models are plotted for comparison. OCDM model is the solid line ( $\Omega = 0.3$ ,  $\Lambda = 0.0$ ) and  $\Lambda$ CDM the dotted line ( $\Omega = 0.3$ ,  $\Lambda = 0.7$ ). The data is consistent with both models. Only the number counts as a function of redshift can distinguish both models.

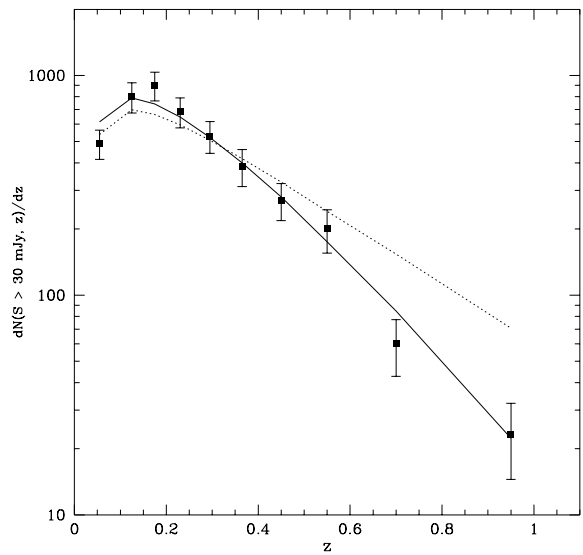


Fig. 2. Evolution of the number counts for the subsample of 300 clusters. The data points were obtained from a Montecarlo simulation of the  $\Lambda$ CDM model. The solid line is the mean expected number counts for the same model ( $\Lambda$ CDM) and the dotted line is the corresponding expected number counts for the OCDM model. The OCDM model is excluded at  $3\sigma$  level.

final catalogue will have a large proportion of high redshift clusters. It is interesting to exploit this fact and study the cosmological implications of such a large and redshift-independent catalogue. Unfortunately, since the SZE is independent of redshift, it will not be possible to determine the redshift of the clusters by just looking at their SZE emission. This fact will limit the kind of cosmological studies which can be done with the Planck catalogue since the only observable will be the flux of the cluster. In Fig. 1 we show the expected number counts for the Planck catalogue as a function of the observed flux.

Despite the large number of clusters in the catalogue, this number will not be enough to discriminate between a model with a cosmological constant and a model without cosmological constant.

However, both models can be distinguished if one uses the evolution of the number counts with redshift. To build this data one needs, obviously, to estimate first the redshift of the clusters and since this can not be done through the SZE one should make an independent optical observation for each one of the clusters. This can be a huge task if one attempts to measure the redshift for each one of the expected 30000 clusters. Some of them will be nearby clusters and they can be easily identified in previous surveys like the Sloan. Others at intermediate redshift could be observed with medium-size telescopes. There will be however, a large number of high- $z$  clusters. In these cases, a large telescope like GTC will be needed. But even observing only the high- $z$  clusters, their expected number is still too large to make a project like this one possible. However, instead of trying to identify all the Planck cluster catalogue, one could try to estimate the redshifts for only a small portion of it and build the number counts (as a function of  $z$ ) from them. The question now is, how small should be the subsample of clusters if we want to extract useful information about the cosmological information from that subsample?

In Diego et al. (2001) we computed such number and we found that due to the particular selection function of Planck, by randomly selecting a subsample of only 300 clusters we could discriminate between  $\Lambda$ CDM and a OCDM models. This is an important conclusion since it tells us that we do not need to identify all the clusters in the Planck catalogue. The selection function of Planck is such that, a random subsample of 300 clusters contain enough high- $z$  clusters to make possible the distinction between the two models.

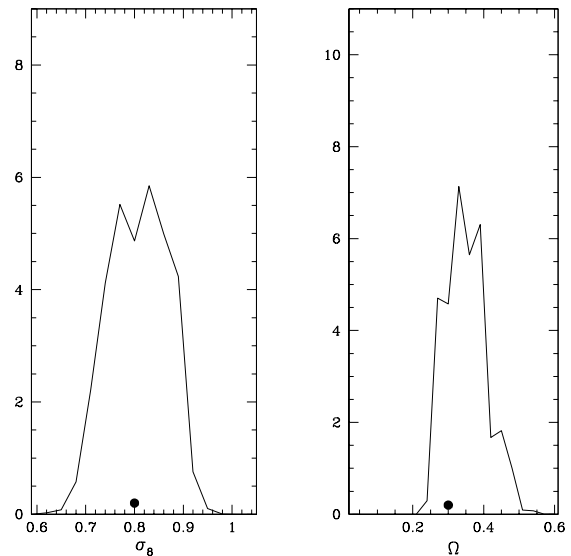


Fig. 3. Cosmological constraints (marginalized probability) obtained after combining the Planck number counts (Fig. 1) with the evolution of the number counts of the optically observed subsample of 300 clusters (Fig. 2). The fiducial model used to simulate the two data sets is indicated by the big black dots.

As we suggested before, part of those 300 clusters could be identified with existing cluster catalogues. Others could be identified using medium-size telescopes and only a small portion of them ( $\approx 20\%$ ) would require a telescope like GTC. In the same paper we calculated that, in order to estimate the photometric redshifts for the most distant clusters with GTC, we should observe them with two hours of integration time (8 bands and 900s per band) per cluster. These numbers show that this is a feasible project and the evolution of the number counts of the SZE-selected subsample of 300 clusters could be determined.

In Fig. 2 we show the expected number counts as a function of redshift for a Montecarlo realization of the  $\Lambda$ CDM model. Also plotted are the mean number counts for the  $\Lambda$ CDM (solid line) and for the OCDM model (dotted line). As we mentioned earlier, with just 300 clusters the OCDM model could be excluded by the high- $z$  bins.

By combining the two data sets (number counts of Planck (Fig 1) and evolution of the number counts of the subsample (Fig. 2)) it is possible to constraint the cosmological parameters of the  $\Lambda$ CDM model.

The first data set is very good to constrain the  $\sigma_8 - \Omega$  correlation. The second data can be used

to break the previous degeneracy between both parameters. The result of combining the Planck number counts (30000 clusters, Fig. 1) with the GTC followup (300 clusters, Fig. 2) can be seen in Fig. 3.

### 3. CONCLUSIONS

We have seen how combining two very different instruments (Planck and GTC) it is possible to constrain the cosmological model. Planck will provide a unique way of selecting distant clusters. However a subsequent redshift estimation will be needed. We have seen that a subsample (randomly selected from the Planck catalogue) of 300 identified clusters is large enough in order to distinguish between a  $\Lambda$ CDM and a OCDM model. Among these 300 clusters there will be many of them which can be identified using existing galaxy cluster catalogues or medium-size telescopes but there will be a portion ( $\approx 20\%$ ) which will require a telescope like GTC. A survey made with GTC over the SZE-selected subsample will allow to constrain the cosmological model in an independent test.

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